United States Patent [19]

Harrison, III et al.

[11] **3,723,803**

[45] **Mar. 27, 1973**

[54] **GENERATION, DISPLAY AND ANIMATION OF TWO-DIMENSIONAL FIGURES**

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[22] Filed: **July 6, 1970**

[21] Appl. No.: **52,389**

[52] **U.S. Cl.**.....**315/22,** 315/18, 340/324 A

[51] **Int. Cl.**.....**H01j 29/70**

[58] **Field of Search**....315/18, 22, 26, 27; 340/324 A

[56] **References Cited**

UNITED STATES PATENTS

3,539,860	11/1970	Max et al.	340/324 A
3,555,538	1/1971	Henderson et al.	315/18
3,364,382	1/1968	Harrison	315/22
3,594,756	7/1971	Granberg	340/324 A

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[57] **ABSTRACT**

A system for automatically generating, displaying and animating two-dimensional figures comprising straight line segments, animations of the figures including gross size, gross position, shape and rotational animation sequences. Means are also provided for maintaining the figure closed through any animation sequence and establishing boundary conditions for the figure.

23 Claims, 12 Drawing Figures

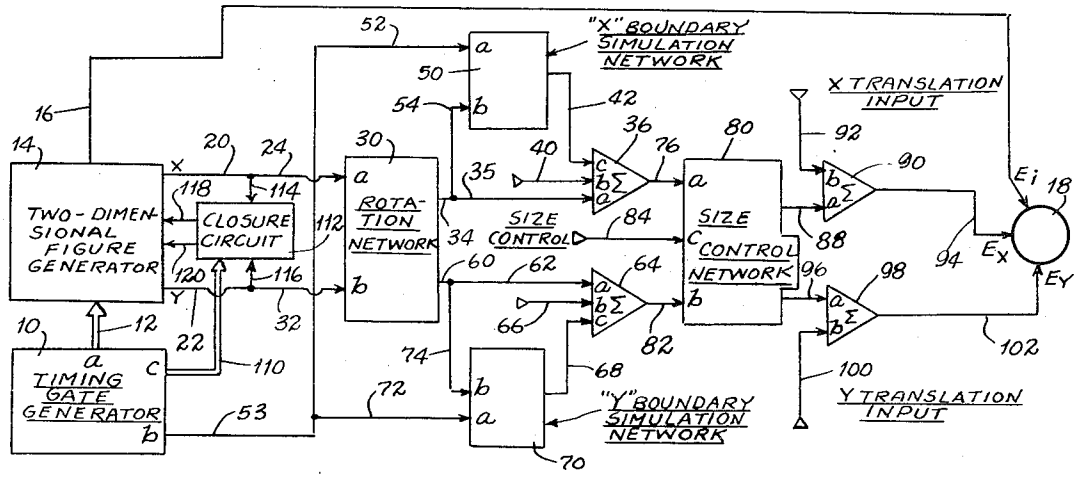

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Fig. 1.

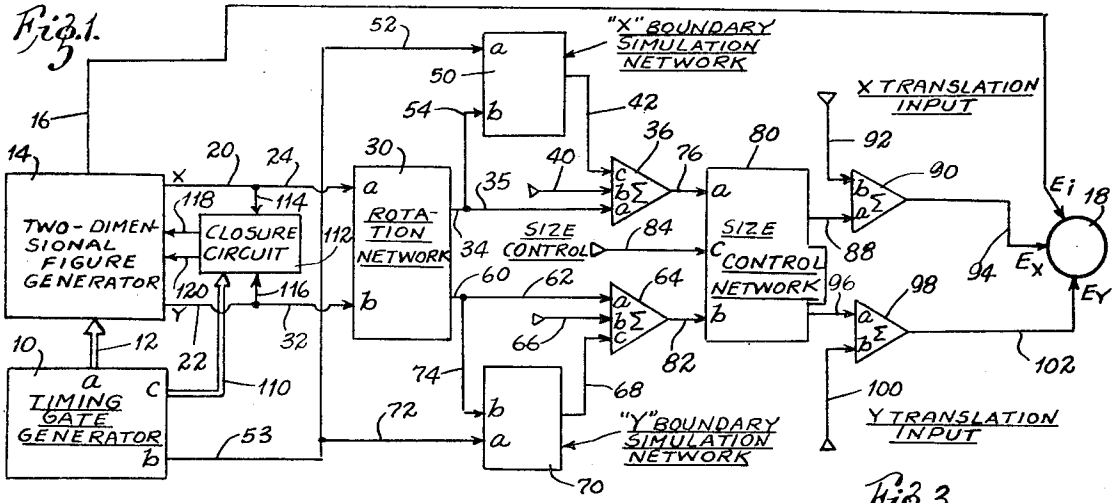

Fig. 2.

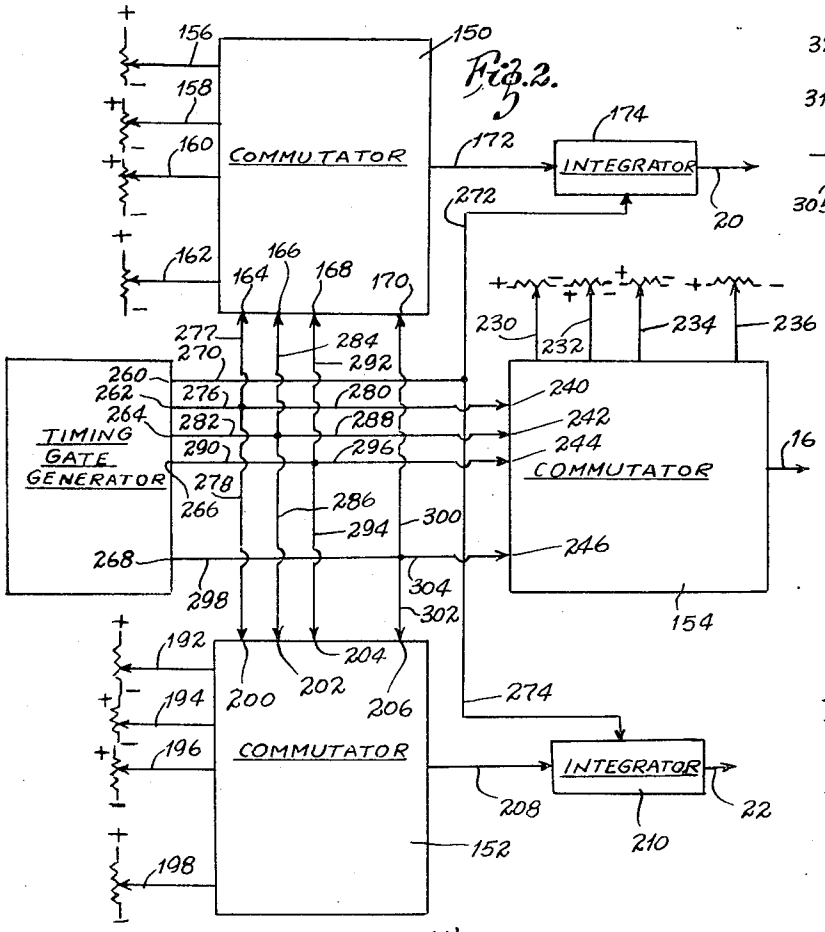

Fig. 3.

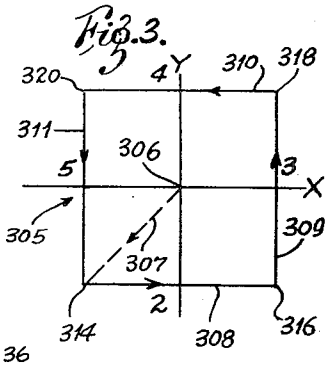

Fig. 5.

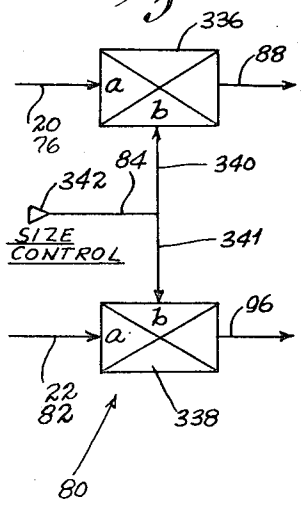

Fig. 6.

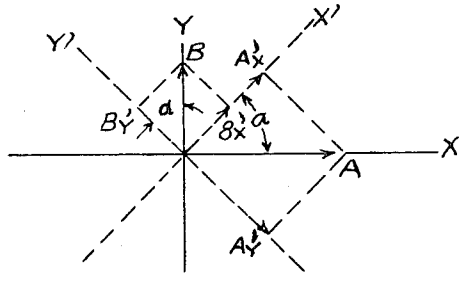

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Fig. 4

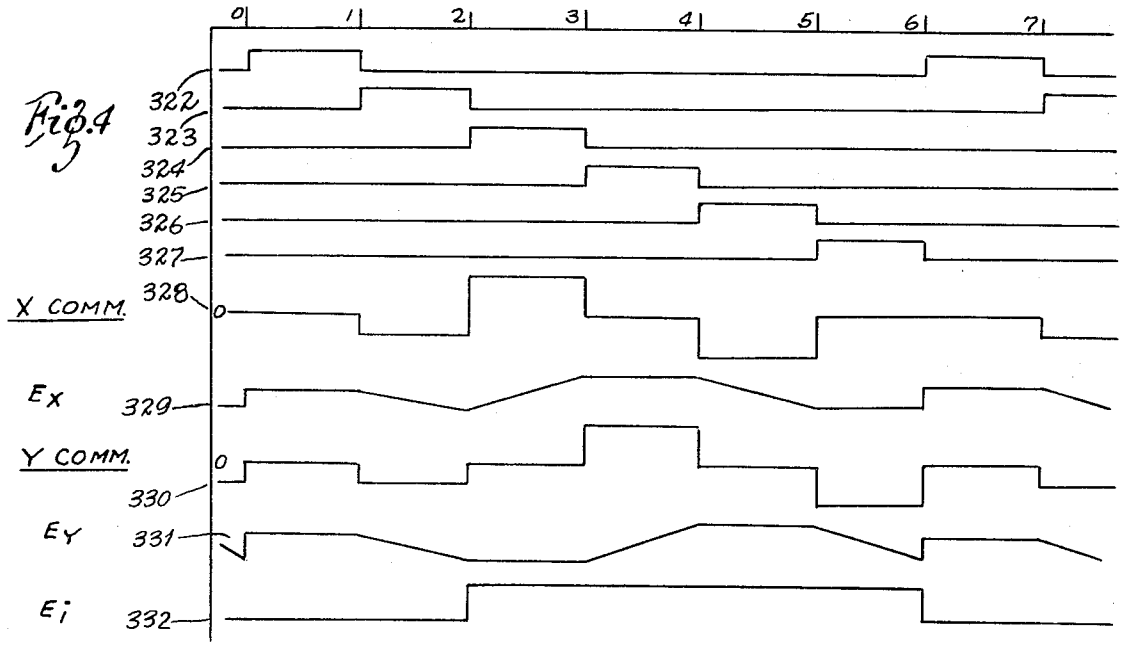

Fig. 7.

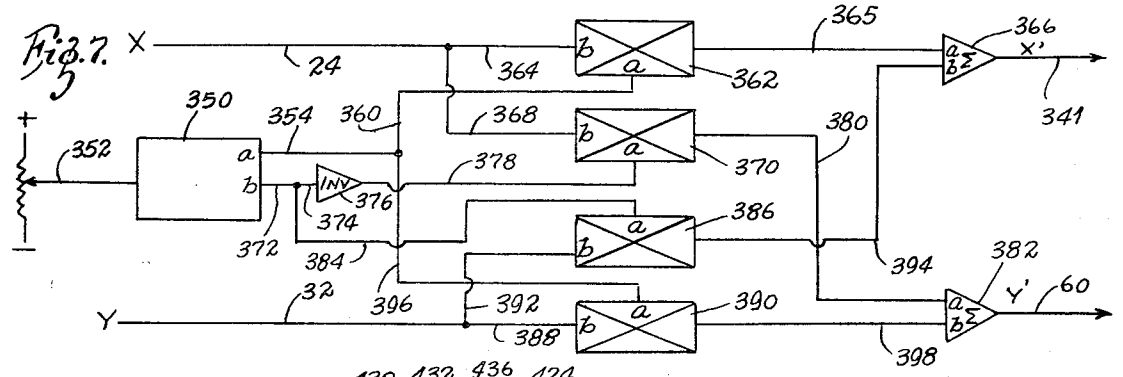

Fig. 8.

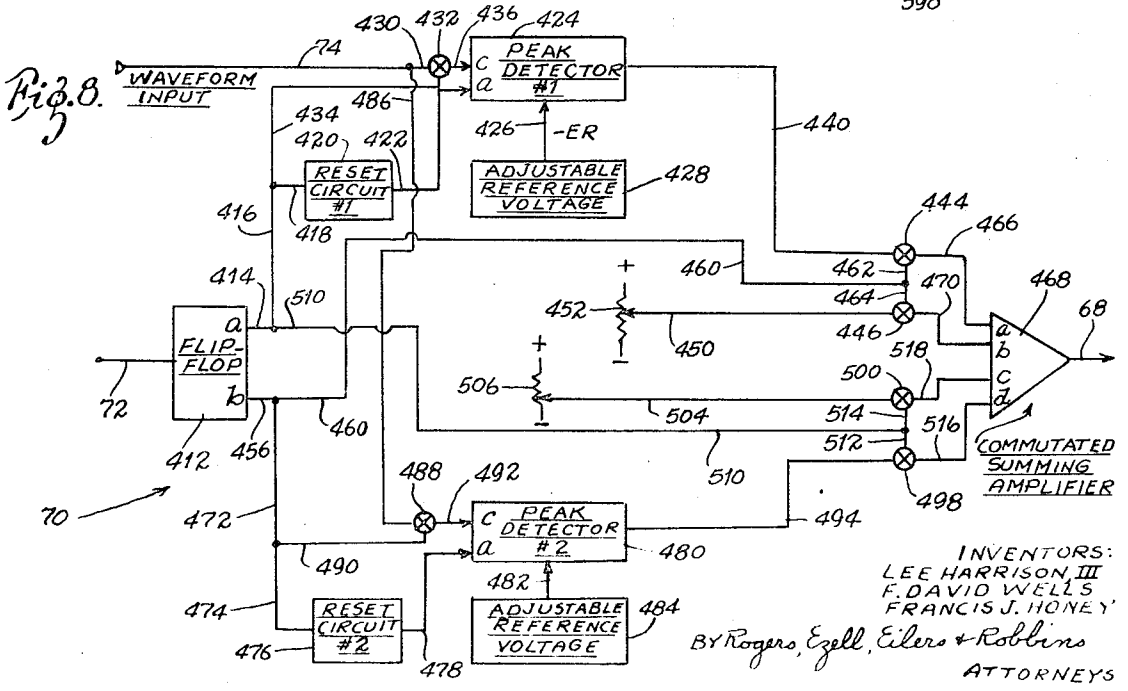

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Fig. 9.

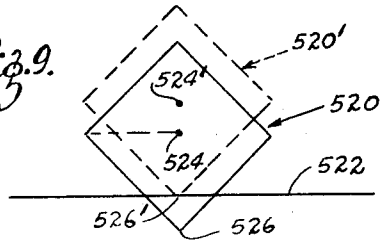


Fig. 12.

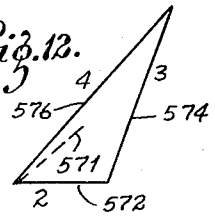


Fig. 10.

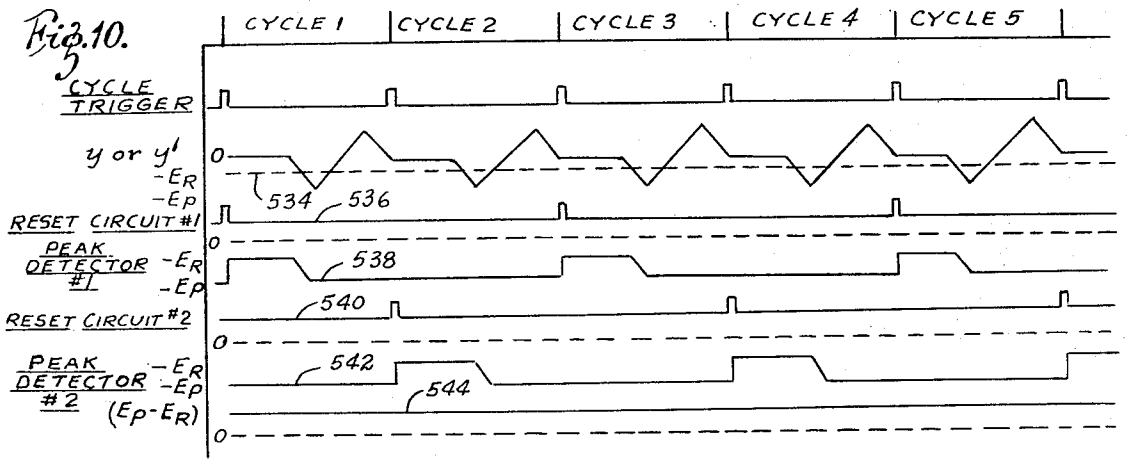
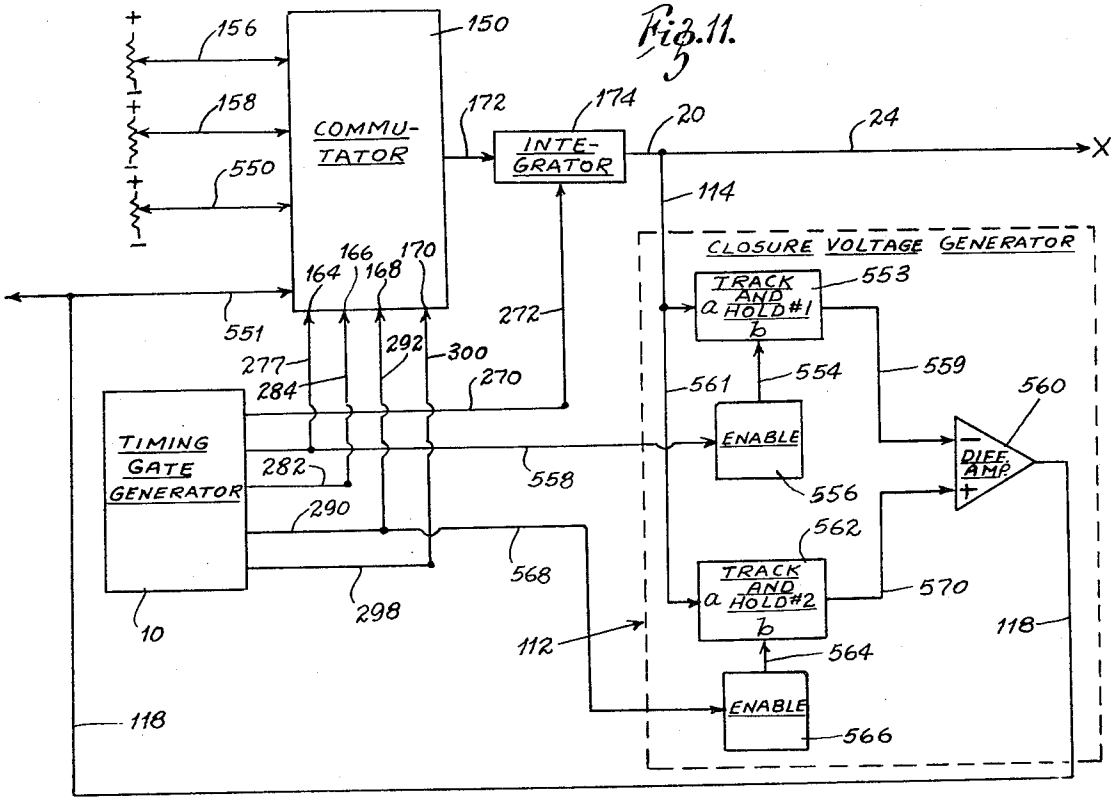


Fig. 11.



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GENERATION, DISPLAY AND ANIMATION OF TWO-DIMENSIONAL FIGURES

BRIEF DESCRIPTION OF THE INVENTION

In general the system for generating, displaying and animating two-dimensional figures includes a cathode ray tube on which the figures are displayed. The cathode ray tube has inputs corresponding to the X, Y, and intensity parameter signals for each segment of the figure. Also included is a two-dimensional figure generator that sequentially generates signals defining each of the line segments of the figure, a timing gate generator which sequentially gates the signals generated by the two-dimensional figure generator, a closure circuit that automatically maintains the figure closed through any animation sequence, a rotation network that transposes the vectors corresponding to each of the line segments generated from one set of coordinants to a second set of coordinants, the second set being rotated at a prescribed angle with respect to the first set, thereby effectively imparting rotation to the figure, a boundary simulation network that establishes boundary conditions in the X and/or Y position to give the figure, in an animation sequence, the appearance of moving in a gravity field, a size-control network which can be used to change the total size of the figure in either the X direction or Y direction and a gross position network for changing the gross position of the figure on the CRT.

With the horizontal sweep of the cathode ray tube beam being thought of as movement in the X direction, and vertical movement of the beam thought of as a movement in the Y direction, the two-dimensional figure generator establishes signals for conventional horizontal and vertical movements of the cathode ray tube beam for generation of each line segment of the figure sequentially. Simultaneous with the generation of each line segment the two-dimensional figure generator generates a signal which is fed to the intensity input of the CRT for defining the intensity of each line segment. The sequential generation of each line segment is accomplished by programming the time gate generator to sequentially generate a series of pulses corresponding to the number of line segments in the figure. These pulses are used to gate commutators having X, Y, and intensity input voltages for generation of each line segment. As these voltages are gated through the commutators, they are integrated and applied to the X, Y, and intensity inputs of the CRT, thus generating the basic two-dimensional figure.

Rotation is imparted to the figure by feeding the X and Y signals for each of the line segments from the two-dimensional figure generator into a rotation network which modifies these signals by transforming them to a new coordinant system rotated through a prescribed angle to the coordinant system of the two-dimensional figure generator. This angle of rotation is defined by a voltage input to the rotation network. As the voltage input is varied, the angle of rotation is varied, and the figure is caused to rotate. Any means for varying this voltage can be used, including a time varying means.

The shape of the figure is changed by varying the X and Y voltage inputs to the commutators of the two-dimensional figure generator. A change in one or more

of these voltages will impart a change in the angle and/or length of one or more line segments of the figure, thereby changing the shape of the figure. To maintain the figure closed during an animation that changes the shape of the figure, a closure circuit is provided that detects the final value of the first line segment generated and the final value of the second to last line segment generated and automatically generates X and Y signals for generation of the last line segment to automatically close the figure. This feature is particularly important where the animation sequence requires a continuing change in the shape of the figure.

The figure can be further animated by use of the size control network. By this network the X and Y signals for each of the line segments are multiplied by size control voltages from either a potentiometer input or a time varying input such as a ramp function. By appropriate selection of the size control voltage the gross size of the figure can be changed in a variety of animation sequences. For example, if a ramp function is used, the gain of the multiplier may be varied from **0** to a maximum producing a corresponding change in the size of the figure. Animation adds a three-dimensional effect, giving the appearance that the figure is moving away from the viewer as it becomes smaller and toward the viewer as it becomes larger.

Gross position animation is accomplished by adding a voltage at the X and Y inputs of the CRT to the X and Y signals from the figure generation network. These position voltages will simply move the origin of the figure causing movement of the figure on the viewing screen. Here again, a time varying function such as a ramp function can be used, in which case the figure can be made to move across the screen from a predetermined initial position to a predetermined final position. This feature can be very useful in an animation sequence such as for example, in combination with the rotation network to cause the figure to roll across the screen.

Included in this invention is a network for establishing simulated boundary conditions for the figure during an animation sequence. Examples are a floor or wall to give the figure the appearance of moving in a gravity field. If, for example, a square is made to roll across a floor the corners of the square must not drop below the level of the floor. Therefore, to simulate the floor condition an offset voltage is generated by the boundary simulator network of a value sufficient to lift the figure the exact amount necessary so that the corners of the square strike the floor as the square rotates. The boundary network includes peak detectors for detecting the negative peak voltage of the figure for each cycle of the figure generated, and means for generating an offset voltage equal to the difference between the peak detector voltage and a voltage defining the boundary condition. This offset voltage is then added to the appropriate coordinant voltage which in this case would be the Y coordinant voltage for application to the CRT.

As can be seen, any two-dimensional straight line figure can be generated by this technique, and, by appropriate combinations of the various animations techniques included in this invention, a great variety of animation sequences can be produced. By this invention, figures such as triangles, squares, parallelograms, and many others can be made to literally dance on the

screen, taking on human characteristics. Much of the animation can be produced automatically by use of generators producing time-varying functions. However, animation can also be produced manually such as by the use of potentiometer inputs to provide the operator with great flexibility of artistic creation.

DESCRIPTION OF THE DRAWINGS

FIG. 1 is a block diagram of the system of this invention;

FIG. 2 is a schematic diagram of the figure generator;

FIG. 3 is an example of the type of figure that can be generated, displayed and animated by the system of this invention and is used as an example to explain the operation of a portion of the system;

FIG. 4 are waveforms generated by the network of FIG. 2 in generating the square of FIG. 3;

FIG. 5 is a schematic diagram of the size control network;

FIG. 6 is a diagram used for describing a coordinate transformation;

FIG. 7 is a schematic diagram of the coordinate transformation network;

FIG. 8 is a schematic diagram of the boundary simulation network;

FIG. 9 is a square used in explaining the operation of the boundary simulation network of FIG. 8;

FIG. 10 are the waveforms generated by the network of FIG. 8 in producing the boundary conditions of FIG. 9;

FIG. 11 is a schematic diagram of the closure network; and

FIG. 12 is a drawing of a triangle used in explaining the operation of the closure network of FIG. 11.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In FIG. 1 there is shown a general block diagram of the system of this invention. There is shown a timing gate generator **10** which, as will be described, operates as a master control for the operation of the system. Control signals from the output *a* of the timing gate generator **10** are fed through a cable **12** to a two-dimensional figure generator **14**. It is the two-dimensional figure generator **14** that generates X coordinate, Y coordinate, and intensity signals for ultimate generation of the basic figure. The intensity signals for each line segment of the figure are fed through a conductor **16** to the intensity input E_i of a cathode ray tube (CRT) **18**, the X coordinate signals are fed through a conductor **20**, and the Y coordinate signals are fed through a conductor **22**. The conductors **20** and **22** could be connected directly to the E_x and E_y inputs, respectively, of the CRT **18** to produce a display of a two-dimensional figure on the CRT; however, certain modifications are made to these signals before they are fed into the CRT **18**, to provide a variety of animation modes. Hence, the X deflection signal on the conductor **20** is fed through a conductor **24** to the input *a* of a rotation network **30**. Likewise, the Y output signal of the conductor **22** is fed through a conductor **32** to the input *b* of the rotation network **30**. The rotation network **30** is a network that transforms the signals referenced by the original XY coordinate system to a new X'Y' coordinate system. As will be described, it is the rotation network **30** that imparts rotational animation to the figure.

The X' output signal from the rotational network **30** is fed through a conductor **34** and a conductor **35** to the input *a* of the summation amplifier **36**. The summation amplifier **36** has an input *b* which receives a signal set by a potentiometer (not shown) through a conductor **40** representing the final X position of the figure. The summation amplifier **36** also has an input *c* connected by a conductor **42** to an X boundary simulation network **50**. The network **50** has an input *a* connected by a conductor **52** and a conductor **53** to an output *b* of the timing gate generator **10**, and an input *b* connected by a conductor **54** to the conductor **34**. The conductor **54** carries the X' signals from the rotation network **30** to the input *b* of the network **50**. As will be described, it is the X boundary simulator network **50**, upon receiving a trigger pulse from the timing gate generator **10** through the conductors **52** and **53**, that establishes X coordinate boundaries for the figure.

The signals representing Y' are fed through a conductor **60** and a conductor **62** to the input *a* of a summation amplifier **64**. The amplifier **64** has an input *b* that receives a signal through a conductor **66** representing the final Y position of the figure, and an input *c* connected by a conductor **68** to a Y boundary simulation network **70**. The network **70** has an input *a* connected by a conductor **72** and the conductor **53** to the output *b* of the timing gate generator **10**. The network **70** also has an input *b* connected by a conductor **74** and the conductor **60** to the Y' output of the rotation network **30**. As will be described, it is the Y boundary simulator network **70**, upon receiving a trigger pulse from the timing gate generator **10** through the conductors **53** and **72**, that establishes Y coordinate boundaries for the figure.

The output signals from the summation amplifier **36**, which represent a varying relationship among the rotation animation signals X', the X boundary limitation signal, and a final X position signal, are fed through a conductor **76** to the input *a* of a size control network **80**. The size control network **80** also has an input *b* connected by a conductor **82** to the output of the summation amplifier **64**. The conductor **82** carries the signals representing a varying relationship among rotational animation Y' with boundary limitations and final Y position. The size control network **80** also has an input *c* which receives size control signals through a conductor **84**. It is the size control network **80** that provides animation of the total size of the figure, this size animation being a function of the signals to the input *c* of the network **80**. Signals representing rotation animation signals X', the X coordinate of each line segment with boundary limitations, a final X position signal, and size animation are fed through a conductor **88**, to the input *a* of a summation amplifier **90**. The summation amplifier **90** also has an input *b* that receives signals through a conductor **92** defining the gross X position of the image on the CRT **18**. The signal from the summation amplifier **90** is fed through a conductor **94** to the E_x input of the CRT **18**. Signals representing the Y position of each line segment of the figure, rotation animation signals Y' with boundary limitations, a final Y position signal, and size animation are fed through a conductor **96** to the input *a* of a summation amplifier **98**. The summation amplifier **98** has an input *b* that receives signals through a conductor **100** defining the gross Y position of the image on the CRT **18**. The output signals from the sum-

mation amplifier **98** are fed through a conductor **102** to the E_y input of the CRT **18**.

The timing gate generator **10** also has an output *c* connected by a cable **110** to the gate input of a closure circuit **112**. It is the closure circuit **112** that automatically generates signals to close the figure as the shape of the figure is changed. The X coordinate signals on the conductor **20** are also fed through a conductor **114** to the closure circuit **112**, and the Y coordinate signals on the conductor **22** are also fed through a conductor **116** to the closure circuit **112**. The circuit **112** sends X and Y coordinate signals for automatic generation of the last line segment of the figure through the conductors **118** and **120**, respectively, to the two-dimensional figure generator **14**.

The technique of generating two-dimensional figures and animating these figures in a variety of animation modes has been generally described. A more detailed description of each of the major components of the system follows.

TWO-DIMENSIONAL FIGURE GENERATION

The circuit for the two-dimensional figure generator **14** is shown in more detail in FIG. **2**. By this circuit, the line segments of the figure to be produced are generated in sequence by commutating voltages representing each line segment. Hence, there are shown three commutators, **150**, **152**, and **154**. Each commutator has a plurality of potentiometer inputs. There are as many potentiometer inputs as there are line segments in the figure to be generated. In the commutator **150**, a potentiometer input **156** sets the X voltage for the first line segment, a potentiometer input **158** sets the X voltage for the second line segment, a potentiometer input **160** sets the X voltage for the third line segment, and so on, to a potentiometer input **162** which sets the X voltage for the nth line segment of the figure. The commutator **150** also has a gate input for each of the potentiometer inputs **156–162**. Hence, the potentiometer input **156** has associated with it a gate input **164**, the potentiometer input **158** has associated with it a gate input **166**, the potentiometer input **160** has associated with it a gate input **168**, and the potentiometer input **162** has associated with it a gate input **170**. When a gate pulse of a given width is fed into the gate input **164**, the commutator **150** generates a voltage at an output conductor **172** equal to the potentiometer input voltage **156** for the duration of the gate pulse. When a gate pulse of a given width is fed into the input **166**, the potentiometer input voltage **158** appears at the output conductor **172**, and so on for each potentiometer input and its corresponding gate input. The sequence X signals generated by the commutator **150** is fed through the conductor **172** to an integrator **174**. The integratated output from integrator **174** is fed through the conductor **20** which can be connected directly to the E_x input of the CRT **18**, or to the input of an animation network such as the rotation network **30** or size control network **80**.

A commutator **152** operates in exactly the same manner as the commutator **150**, except it is used to commutate Y voltages. Hence, a potentiometer input **192** sets the Y voltage for the first line segment, a potentiometer input **194** sets the Y voltage for the second line segments, a potentiometer input **196** sets the Y voltage for the third line segment, and a potentiometer input **198** sets the Y voltage for the nth line segment of the figure. Associated with each of the potentiometer inputs **192 – 198**, is a gate input. The potentiometer input **192** has associated with it a gate input **200**, the potentiometer input **194** has associated with it a gate input **202**, the potentiometer input **196** has associated with it a gate input **204**, and the potentiometer input **198** has associated with it a gate input **206**. Just as with the commutator **150** when a gate pulse is fed sequentially to each of the gate inputs **200 – 206**, the corresponding potentiometer input signal is fed through the commutator **152** and an output conductor **208** to an integrator **210**. The integrated output from the integrator **210** is fed through the conductor **22**. Like the output from the integrator **174**, the output from the integrator **210** can be fed directly to the E_y input of the CRT **18**, or to the input of an animation network such as the rotational network **30** or size control network **80**.

A commutator **154** operates in exactly the same manner as the commutators **150** and **152** except it is used to commutate intensity voltages. Hence, a potentiometer input **230** sets the intensity voltage for the first line segment, a potentiometer input **232** sets the intensity voltage for the second line segment, a potentiometer input **234** sets the intensity voltage for the third line segment, and a potentiometer input **236** sets the intensity voltage for the nth line segment. Associated with each of the potentiometer inputs **230 – 236** is a gate input. Hence, the potentiometer input **230** has associated with it a gate input **240**, the potentiometer input **232** has associated with it a gate input **242**, the potentiometer input **236** has associated with it a gate input **246**. Just as with the commutators **150** and **152**, when gate pulses of fixed width are sequentially fed into the gate inputs **240 – 246** of the commutator **154**, the commutator **154** generates at its output the corresponding potentiometer input voltage. Because it is usually desirable to have a constant intensity level for each line segment on the CRT **18** and because a constant intensity is determined by a DC voltage, the sequential DC output voltages from the commutator **154** are fed through the conductor **16** directly to the E_i input of the CRT **18**.

The appropriate voltage levels are now set for generation of each of the line segments of the figure; however, it is necessary to establish a time sequence for generating each of the line segments. This is accomplished by the timing gate generator **10**. The timing gate generator **10** is a sequential pulse generator having a plurality of outputs **260**, **262**, **264**, **266**, and **268**. There could be any number of outputs, the output **268** corresponding to the nth output. The generator **10** can be programmed to generate pulses of given widths in sequence at its outputs. The first pulse generated by the generator **10** will appear at the output **260** and be fed through a conductor **270** and a conductor **272** to the reset input of the integrator **174**. The pulse on the conductor **270** is also fed through a conductor **274** to the reset input of the integrator **210**. Hence, the pulse at the output **260** resets each of the integrators **174** and **210** to zero. The next pulse generated by the generator **10** appears at the output **262** and is fed through a conductor **276** and a conductor **277** to the gate input **164**

of the commutator **150**. The pulse on the conductor **276** is also fed through a conductor **278** to the gate input **200** of the commutator **152**. The pulse on the conductor **276** is also fed through a conductor **280** to the gate input **240** of the commutator **154**. Hence, the pulse at the output **262** of the generator **10** simultaneously gates each of the commutators **150, 152,** and **154** to produce X, Y, and intensity signals for the generation of the first line segment. The next pulse generated by the generator **10** appears at the output **264** and is fed through a conductor **282** and a conductor **284** to the gate input **166** of the commutator **150**. The pulse on the conductor **282** is also fed through a conductor **286** to the gate input **202** of the commutator **152**. The pulse on the conductor **282** is also fed through a conductor **288** to the gate input **242** of the commutator **154**. Hence, the pulse at the output **264** of the generator **10** simultaneously gates each of the commutators **150,152,** and **154** to generate signals for generation of the second line segment. The third pulse generated by the generator **10** appears at the output **266** and is fed through a conductor **290** and a conductor **292** to the gate input **168** of the commutator **150**. The pulse on the conductor **290** is also fed through a conductor **294** to the gate input **204** of the commutator **152**. The pulse on the conductor **290** is also fed through a conductor **296** to the gate input **244** of the commutator **154**. It is the pulse at the output **266** of the generator **10** that simultaneously gates the commutators **150, 152** and **154** to generate signals for generation of the third line segment. There may be any number of additional pulses from the generator **10** but the last or nth, pulse generated at the output **268** is fed through a conductor **298** and a conductor **300** to the gate input **170** of the commutator **150**. The pulse on the conductor **298** is also fed through a conductor **302** to the gate input **206** of the commutator **152**. The pulse on the conductor **298** is also fed through a conductor **304** to the gate input **246** of the commutator **154**. It is the pulse at the output **268** of the generator **10** that simultaneously gates each of the commutators **150, 152** and **154** to generate signals for generation of the nth line segment. After the nth pulse is generated, the pulse sequence is repeated with the next pulse generated at the output **260** for resetting the integrators **174** and **210** to zero.

By way of example, the operation of the circuit of FIG. **2** will be explained for the generation and display of the square of FIG. **3** on the CRT **18**. In FIG. **3**, there is shown a square **305** with a center **306** and comprised of line segments **307, 308, 309, 310,** and **311**. The segment **307** is used to position the square so that the origin is at the center **306**. Therefore, the center of the square is at the coordinate $x = 0$, $y = 0$, on the xy coordinates shown. The end of the first line segment **306** is a corner **314** of the figure, having coordinates x_1 y_1. The end of the line segment **308** is a corner **316** having coordinates x_2y_2. The end of the line segment **309** is a corner **318** having coordinates x_3y_3. The end of the line segment **310** is a corner **320** having coordinates x_4y_4. Finally, the end of the line segment **311** is the corner **314** having coordinates x_5y_5. Because the FIG. **306** is a closed figure, the coordinates x_5y_5 are the same as the coordinates x_1y_1. Because there are five line segments (**307-311**) that must be generated, each of the commutators **150,152** and **154** must have five potentiometer inputs and five gate inputs. Also, the timing gate generator **10** must have a total of six outputs, one for resetting the integrators **174** and **210**, and five for gating the five potentiometer inputs to each of the commutators. The X voltages for generation of each of the line segments **307 – 311** are set on the potentiometer inputs to the commutator **150**, the Y voltages are set on the potentiometer inputs to the commutator **152**, and the intensity voltages are set on the potentiometer inputs to the commutator **154**. The timing gate generator **10** is programmed to sequentially generate six pulses of equal width per cycle at its output.

The generation of the square of FIG. **3** can now be explained with reference to the wave forms of FIG. **4**. The wave forms **322, 323, 324, 325, 326** and **327** are the sequential pulses generated at the six outputs of the timing gate generator **10**. The first of these pulses as shown by the wave form **322**, is the reset pulse for the integrators **174** and **210**. The remaining pulses, as shown by wave forms **323 – 327**, sequentially gate each of the commutators **150, 152** and **154**. The output of the X commutator **150** for the entire cycle of the timing gate is shown by the wave form **328**. During the reset pulse, as shown by the wave form **322**, the signal of the wave form **328** is zero, since no line segments are generated when the integrators **174** and **210** are reset. The remainder of the wave form **328** represents the voltages set by the potentiometer inputs for the commutator **150**, for generating the X signals for each of the line segments. The wave form **328** is integrated by the integrator **174** with the integrated output on the conductor **20** shown by the wave form **329**. The reference level of the wave form **329** can be varied as will be hereinafter described to move the gross position of the square of FIG. **3** along the X axis.

For now, assume the origin of the square of FIG. **3** is zero, with respect to both the X and Y axis so that the reference level of the wave form **329** is zero.

The output of the Y commutator **152** for generating the square of FIG. **3** is shown by the wave form **330**. Just as with the wave form **328**, the wave form **330** is zero during the resetting of the integrators **174** and **210**. The remainder of the wave form **330** represents the voltages set by the potentiometer inputs to the commutator **152** for generating the Y signals for each of the line segments. The wave form **330** as integrated by the integrator **210** is shown by the wave form **331**. Again, assuming the origin of the square of FIG. **3** is zero, with respect to both the X and Y axis, the reference level of the wave form **331** is also zero.

Finally, the output from the commutator **154**, representing the intensity of each of the line segments, is shown by the wave form **332**. It can be seen from the wave form **332** that during a single generation cycle only the line segments **308 – 311** are intensified. The line segment **307** is not intensified, as it is used only to position the square with its origin at the center. In this example, the intensity level of all the sides of the square is held constant by the constant level of the wave form **332**. If desired, of course, the potentiometers **230 – 236** could be adjusted to vary these intensities.

The wave forms **329, 331,** and **332** can be applied directly to the E_x, E_y and E_i inputs, respectively, of the CRT **18** to produce the square of FIG. **3**. Using this basic technique, any straight line, two-dimensional figure can be generated and displayed.

This invention also provides a means for animating the figure by varying one or more of the potentiometer inputs to the commutators **150** and **152**. Obviously, variations in one or more of these inputs will change the shape of either or both of the X and Y coordinate waveforms, thereby causing a change of form in the figure. By manipulating these inputs as the timing gate generator **10** cycles, the operator of the system can animate the figure in a great variety of sequences that include variations in size, orientation, position and shape.

GROSS POSITION ANIMATION

Referring to FIG. **1** the summation amplifiers **36** and **64** and their corresponding inputs make up the circuit for adjusting the gross position of the image on the CRT **18**. Each of the summation amplifiers **36** and **64** have inputs *a*, *b*, and *c*. The input *a* of the summation amplifier **36** is shown connected by the conductor **35** to the X′ output from the rotation network **30**. However, if the rotation network **30** is not used, the input *a* could be connected directly by the conductor **20** to the X output from the two-dimensional figure generator **14**. The input *b* of the summation amplifier **36** is connected by the conductor **40** to an X gross position voltage function. The voltage function can be a constant voltage set by a potentiometer or a time varying function such as a ramp function. As previously stated, the input *c* of the summation amplifier **36** is connected to the output of the boundary simulation network **50** which will be hereinafter described in detail. Likewise, the input *a* of the summation amplifier **64** is shown connected by the conductor **62** to the Y′ output of the rotation network **30**. However, the input *a* could also be connected by the conductor **22** directly to the Y output of the two-dimensional figure generator **14**. The input *b* of the summation amplifier **64** is connected by a conductor **66** to a Y gross position voltage function. This voltage function, like the X position voltage function, can be either constant or time varying. The input *c* to the summation amplifier **64** is connected by the conductor **68** to the boundary simulation network **70**, which will be hereinafter described in detail. For now, the *c* inputs to the summation amplifiers **36** and **64** can be ignored. Although the outputs of the summation amplifiers **36** and **64** are shown connected by the conductors **76** and **82**, respectively, to the size control network **80**, these outputs could be connected directly to the E_x and E_y inputs, respectively, of the CRT **18**. With the system so connected, the gross position of the total figure generated by the two-dimensional figure generator **14** can be varied in the X direction by varying the voltage at the input *b* of the summation amplifier **36**, this voltage being added to the X coordinate waveform voltages from the generator **14**, or the Y direction by varying the voltage at the input *b* of the summation amplifier **64**, this voltage being added to the Y coordinate waveform voltages from the generator **14**. By using various combinations of voltages at the *b* inputs of the summation amplifiers, a variety of gross position animation sequences is obtained. For example, if potentiometer inputs are used, these potentiometers can be varied to position the figure anywhere on the CRT **18**. If ramp functions are used, the figure can be made to move across the screen between a predetermined starting position to a predetermined final position.

SIZE ANIMATION

The size of the figure can be varied by use of the size control network shown in more detail in FIG. **5**. The size control network **80** includes analog multipliers **336** and **338** each having inputs *a* and *b*. The *a* inputs can receive signals from a variety of sources including the X and Y coordinate waveforms on the conductors **20** and **22** from the two-dimensional figure generator **14**, or the output from the summation amplifiers **36** and **64**, depending on the network configuration used. The input *b* of the multiplier **336** is connected by a conductor **340** and the conductor **84** to a size control voltage function **342**. The input *b* of the multiplier **338** is connected by a conductor **341** and the conductor **84** to the size control voltage function **342**. The signals at the output conductors **88** and **96** of the multipliers **336** and **338**, respectively, are the product of the signals at the inputs *a* and *b*. Hence, the size control voltage function is fed through the conductors **84** and **340** to the input *b* of the multiplier **336** where it is multiplied by the signals at the input *a* of the multiplier **336** to produce the output signals on the conductor **88**. The size control voltage is also fed through the conductors **84** and **341** to the input *b* of the analog multiplier **338** where it is multiplied by the signals at the input *a* of the multiplier **338** to produce the output signals on the conductor **96**. A variation in the control voltage **342** produces a corresponding variation in the voltages on the output conductors **88** and **96**. For example, if the control voltage **342** is set by a potentiometer the total size of the image can be set wherever desired, or varied by varying the potentiometer. By adjusting the control voltage **342** from full scale to 0, the size of the image on the CRT **18** can be reduced from a maximum down to a point located at the origin of the figure. If the control function **342** is a ramp function, a zooming effect is achieved with the figure zooming from a small size to a large size or vice versa, depending on whether a positive or negative ramp is used. If four-quadrant multipliers are used, the image on the CRT **18** can be invented by applying a negative control voltage to the multipliers. The use of ramp functions to give a zooming effect gives apparent depth or a third dimension to the image.

While FIG. **2** shows a single size control for controlling the gain of the multipliers **336** and **338** simultaneously, it would, of course, be possible to have separate size controls for each multiplier. In this way, the size of the image in the X and Y direction can be selectively controlled. For example, the square of FIG. **3** would become a rectangle by varying the gain of only one of the multipliers.

ROTATIONAL ANIMATION

Another form of animation provided by this system is rotational animation about the point of origin of the figure. If the figure is a square, such as the one shown in FIG. **3**, the rotation would be about the point **306**. Rotation is produced by means of a coordinate transformation. Referring to FIG. **6**, the formulas for rotating the figure will be derived. There are shown XY coordinate axes and X′Y′ coordinate axes. The X′Y′ axes are rotated counter-clockwise through an angle α, the angle α being the angle of rotation. Let the vector

component x equal A, and the vector component Y, equal B, so that A and B are the original vector components on the XY axes.

A_x', B_x', A_y', and B_y' are the components of A and B projected on X' and Y'.

Then,

$$A' = A_x' + B_x'$$

$$B' \; 132 \; B_y' - A_y'$$

$$A_x' = A \cos \alpha$$

$$A_y' = A \sin \alpha$$

$$B_x' = B \sin \alpha$$

$$B_y' = B \cos \alpha$$

$$\text{and } A' = A \cos \alpha + B \sin \alpha$$

$$B' = B \cos \alpha - A \sin \alpha$$

therefore,

$$x' = x \cos \alpha + y \sin \alpha$$

$$y' = y \cos \alpha - x \sin \alpha$$

If clockwise rotation is assumed, the equations become

$$x' = x \cos \alpha - y \sin \alpha \text{and}$$

$$y' = y \cos \alpha + x \sin \alpha$$

The network of FIG. 7 produces the rotational animation. There is shown a sine—cosine generator **350** with a potentiometer input **352**. The setting of the potentiometer input **352** determines the angle α. A detailed description of a suitable sine cosine generator **350** is shown in FIG. 3 of and described in U. S. Pat. No. 3,364,382. For the purposes of this disclosure, it is sufficient to know that the generator **350** generates at an output *a* the cosine of α and at an output *b* the sine of α. The cosine α function at the output *a* is fed through a conductor **354** and a conductor **360** to the input *a* of a multiplier **362**. The function x representing the *x* coordinate voltages of the line segments of the figure, and which corresponds to the signal on the conductor **20** of FIGS. **1** and **2**, is fed through the conductor **24** and a conductor **364** to the input *b* of the multiplier **362**. The output from the multiplier **362** which represents $x \cos \alpha$ is fed through a conductor **365** to the input *a* of a summation amplifier **366**. The signal on the conductor **24** is also fed through a conductor **368** to the input b of a multiplier **370**. The signal at the output *b* of the sin — cos generator **350** representing sin α is fed through a conductor **372** and a conductor **374** to an inverter **376**. The output from the inverter **376** representing $-\sin \alpha$ is fed through a conductor **378** to the input *a* of the multiplier **370**. The output from the multiplier **370** representing $-x \sin \alpha$ is fed through a conductor **380** to the input *a* of a summation amplifier **382**. The signal on the conductor **372** representing sin α is also fed through a conductor **384** to the input *a* of a multiplier **386**. The function *y* representing the *y* coordinate voltages of the line segments of the figure and which corresponds to the signal on the conductor **22** of FIGS. **1** and **2** is fed through the conductor **32** and a conductor **388** to the input *b* of a multiplier **390**. The signal on the conductor **32** is also fed through a conductor **392** to the input *b* of the multiplier **386**. The output from the multiplier **386** representing $y \sin \alpha$ is fed through a conductor **394** to the input *b* of the summation amplifier **366**. The output from the summation amplifier **366** represents $x \cos \alpha + y \sin \alpha$ which is equal to x'. The signal on the conductor **354** representing cos α is also fed through a conductor **396** to the input *a* of the multiplier **390**. The output from the multiplier **390** representing y cos α is fed through a conductor **398** to the input *b* of the summation amplifier **382**. The output from the summation amplifier **382** represents $y \cos \alpha - x \sin \alpha$ which is equal to y'. The x' and y' output signals can be fed directly into the E_x and E_y input of the CRT **18** or first into the size control network **80**, or summation amplifiers **36** and **64**. The network of FIG. **7** could be easily modified in accordance with the above equations to produce clockwise rotation.

Therefore, the image on the CRT **18** can be made to rotate about its origin by varying α through use of the potentiometer input **352**. Obviously, if α is varied continuously through 360°, the figure can be made to rotate continuously. If the gross position network is used simultaneously with the rotation network, the figure can be made to roll across the screen in any direction.

BOUNDARY LIMITATIONS

Figures animated by the techniques described thus far, for example rotational animation, often have the appearance of floating in space because their motion is not constrained by a boundary such as a floor or a wall. They give the illusion of moving around under conditions of zero gravity. It may be desirable to simulate the effects of certain boundary conditions such as a floor or wall in a gravity field. To accomplish this, the circuit shown in FIG. **8** is used. Suppose for example, a floor is to be simulated so that the corners of the square of FIG. **9** appear to contact the floor as the figure rotates much as a square block would roll on a flat surface. As the square rotates about its origin the corners of the square must just contact the surface of the floor. Therefore, as each corner approaches, the entire square must be raised a distance that equals the distance the corners would otherwise extend beneath the floor. This is accomplished by the boundary simulation networks **50** and **70**. As these networks are identical, it is necessary to describe only one in detail.

In FIG. **8**, there is shown the network **70** having a flip-flop **412**. The input of the flip-flop **412** is connected by the conductors **53** and **72** to the output *b* of the timing gate generator **10**. At the beginning of each cycle of pulses generated by the generator **10**, a trigger pulse is generated at the output *b* of the generator **10** in synchronization with the generation of the reset signal on the conductor **270**. This pulse is fed through the conductors **53** and **72** to trigger the flip-flop **412**. The flip-flop **412** has outputs *a* and *b*. Each time the flip-flop **412** receives a trigger pulse it changes state with signal levels alternately appearing at its *a* and *b* outputs. The trigger pulse at the beginning of the first cycle triggers the flip-flop **412** to produce a signal at its output *a* which is fed through a conductor **414**, a conductor **416**, and a conductor **418** to a reset circuit **420**. The output

of the reset circuit **420** is connected by a conductor **422** to the input *a* of a peak detector **424**. The peak detector **424** also has inputs *b* and *c* and is a device that tracks a waveform introduced at its input *c* and stores the peak voltage of the waveform. The input *b* of the detector **424** is connected by a conductor **426** to an adjustable reference voltage **428** which is set to represent the boundary condition. The reference voltage **428** is fed through the conductor **426** to the input *b* of the peak detector **424**. When the peak detector **424** is reset by the signal on the conductor **422**, it will discharge to a voltage level equal to the reference voltage **428** and will hold this voltage until it detects a greater voltage on the waveform it is tracking. If a greater voltage is detected, it will store that voltage. The waveform representing the *y* or *y'* coordinate voltages for each of the line segments is fed through the conductor **74** and a conductor **430** to an analog switch **432**. The signal on the conductor **416** is also fed through a conductor **434** to the analog switch **432**, closing the analog switch at the same time the peak detector **424** is reset to the reference voltage level **428**. When the analog switch **432** closes, the *y* or *y'* waveform on the conductor **430** is fed through a conductor **436** to the tracking input *c* of the peak detector **424**, enabling the peak detector **424** to track the *y* or *y'* waveform and store the peak voltage on that waveform, providing it is greater than the reference voltage **428**. The peak respectively voltage is fed through a conductor **440** to an analog switch **444**. Another analog switch **446** is connected by a conductor **450** to a potentiometer input **452**. The potentiometer input **452** is adjusted to a voltage equal and opposite to the reference voltage **428**. The peak voltage from the peak detector **424** and the voltage from the potentiometer input **452** are applied to the analog switches **444** and **446**, respectively.

At the beginning of the next cycle (after each element of the figure has been generated one time) another trigger pulse will be generated by the timing gate generator **10** which is fed through the conductors **53** and **72** to trigger the flip-flop **412**, causing the flip-flop **412** to change state so that there is a signal at its output *b* and no signal at its output *a*. Because there is no signal at the output *a*, there is no signal on the conductor **434** and the analog switch **432** opens. With the analog switch **432** open, the peak detector **424** will stop tracking and will hold the peak voltage detected before the analog switch **432** opens. The signal at the output *b* of the flip-flop **412** is fed through a conductor **456**, a conductor **460** and a conductor **462** to close the analog switch **444**. The signal on the conductor **460** is also fed through a conductor **464** to close the analog switch **446**. With the analog switches **444** and **446** closed, the peak voltage from the peak detector **424** is fed by the conductor **440** through the analog switch **444** and a conductor **466** to the input *a* of a summing amplifier **468**, and the potentiometer voltage **452** is fed through the conductor **450**, the analog switch **446**, and a conductor **470** to the input *b* of the summing amplifier **468**. The output of the summing amplifier **468** is equal to the algebraic sum of the peak voltage from the detector **424** and the potentiometer voltage **452**. This algebraic sum is the offset voltage.

Another circuit identical to the one just described generates the offset voltage for the next cycle. Two circuits are necessary, each operating on alternate cycles because each peak detector must sample the waveform for an entire cycle before generating the offset voltage for the next cycle. Hence, the signal on the conductor **456** is also fed through a conductor **472**, and a conductor **474** to a reset circuit **476**. The reset circuit **476** is identical to the reset circuit **420**. The output of the reset circuit **476** is fed through a conductor **478** to the input *a* of a peak detector **480**. The peak detector **480** is identical to the peak detector **424** and operates in exactly the same manner. The peak detector **480** has another input *b* connected by a conductor **482** to a reference voltage **484**. Just as with the reference voltage **428**, the voltage **484** is set to represent the boundary condition. When the peak detector **480** receives the signal at the input *a*, it is reset to a value equal to the voltage **484**. The Y' waveform on the conductor **74** is also fed through a conductor **486** to an analog switch **488**. The signal on the conductor **472** is also fed through a conductor **490** to close the analog switch **488**. With the analog switch **488** closed, the Y' waveform is fed through a conductor **492** to the input *c* of the peak detector **480**. Just as with the peak detector **424**, the peak detector **480** tracks the Y' waveform for one complete cycle and stores the peak voltage providing it is greater than the reference voltage **484**. This peak voltage is fed through a conductor **494** to an analog switch **498**. Another analog switch **500** is connected by a conductor **504** to a potentiometer input **506**. The potentiometer input **506** is set to a value equal and opposite to the reference voltage **484**. The peak voltage on the conductor **494** and the voltage from the potentiometer input **506** are applied to the analog switches **498** and **500**, respectively. At the beginning of the third cycle of pulses from the timing gate generator **10**, another trigger pulse is generated to again trigger the flip-flop **412**, causing the flip-flop **412** to change state so that there is a signal at its output *a* and no signal at its output *b*. With no signal at the output *b*, the analog switch **488** opens and the peak detector **480** stops tracking. The signal at the output *a* of the flip-flop **412** is fed through the conductor **414**, a conductor **510**, and a conductor **512** to close the analog switch **498**. The signal on the conductor **510** is also fed through a conductor **514** to close the analog switch **500**. With the analog switches **498** and **500** closed, the peak voltage from the peak detector **480** is fed through a conductor **516** to the input *d* of the summing amplifier **468**, and the voltage from the potentiometer input **506** is fed through the conductor **504**, the analog switch **500** and a conductor **518**, to the input *c* of the summing amplifier **468**. Therefore, the output of the summing amplifier **468** at the beginning of the third cycle is also equal to the algebraic sum of the peak voltage from the detector **480** and the potentiometer voltage **506**, which is the offset voltage. The signal on the conductor **414** which closes the analog switches **498** and **500** is also fed through the conductor **416** to reset the peak detector **424** and close the analog switch **432** to track the Y' waveform for the next cycle. This tracking by each peak detector of alternate cycles continues to generate an offset voltage for each cycle. Referring again to FIG. **1**, this offset voltage is fed through the conductor **68** to the summation amplifier **64** where it is added to the Y' voltages.

While the boundary simulation network **70** just described operates on the Y or Y′ coordinate waveform, this same circuit is used in the simulation network **50** to simulate X coordinate boundary conditions by tracking the X or X′ waveform.

By way of example, the operation of the boundary network **70** will be explained with reference to the square **520** oriented as in FIG. **9** and the waveforms of FIG. **10**. Assume that the conditions to be simulated are the rolling of the square **520** across a floor **522**. The floor **522** being the boundary condition. As the square **520** rotates about its origin **524** each of its corners, such as the corner **526**, must contact the surface of the floor **422** and not extend beneath it. Therefore, as the square **520** rotates, the entire square must be raised a sufficient amount so that each of the corners just contact the floor **522**. For this condition, the square **520** assumes the position of the square **520′** shown by dotted lines in FIG. **9**. The waveform **530** of FIG. **10** shows the trigger pulses generated at the beginning of each cycle by the timing gate generator **10**. These pulses trigger the flip-flop **412**. The waveform **532** is either the Y or Y′ coordinate of the waveform for generating the square **520** of FIG. **9**. In this waveform, the floor **522** is represented by a voltage level $-E_R$ shown by a dotted line **534**, and the negative peak voltage of the waveform is designated $-E_p$. The waveform **532** is tracked by the peak detectors **424** and **480** on alternate cycles as heretofore described with the detectors **424** and **480** holding the negative peak voltage $-E_p$. Each of the reference voltages **428** and **484** are set to equal the voltage representing the boundary condition $-E_R$. Each of the potentiometer inputs **452** and **506** are set to equal $+E_R$ as heretofore described. The waveform **536** is the output waveform from the reset circuit **420** used to reset the peak detector **424**. The waveform **536** is half the frequency of the waveform **530**. The waveform **538** is the output waveform from the peak detector **424**. It will be noted that upon detecting the negative peak voltage $-E_p$ the detector **424** will hold that voltage for the remainder of the cycle and through the next cycle at which time the detector **424** is reset. The waveform **540** is the output waveform from the reset circuit **476** used to reset the peak detector **480**. The waveform **540** is half the frequency of the waveform **530** and is 180° out of phase with the waveform **536** so that they operate on alternate cycles. The waveform **542** is the output waveform from the detector **480**. The output from the detector **480**, as noted by comparing the waveforms **538** and **542**, is 180° out of phase with the output waveform from the detector **424**. On alternate cycles, the summing amplifier **468** computes the algebraic difference between the waveform **542** and the potentiometer input voltage **506** and the waveform **538** and the potentiometer input voltage **452**. These algebraic differences are equal to $E_p - E_R$ as shown by the waveform **544** and are fed through the conductor **68** to the summation amplifier **64** to raise the square **520** to the position of the square **520′**.

CLOSURE NETWORK

Another feature of this invention which provides great versatility in animating certain types of figures, is the automatic closure network. Using the commutating scheme of FIG. **2**, a figure is generated by appropriate adjustment of the X,Y, and intensity potentiometers. Animation is produced by varying these potentiometers. However, in order for the figure to remain closed during an animation sequence, x_n must equal x_1, and y_n must equal y_1. If one or more of the potentiometers are varied without also varying the others, the point $x_1 y_1$ will not equal the point $x_n y_n$, and the figure will come apart. Without a means for automatically driving the last line segment back to the point $x_1 y_1$, it would be very difficult to produce animation. The closure circuit **112** is such a means.

The closure circuit for the X coordinate signals is shown in FIG. **11**. There is an identical closure circuit for the Y coordinate signals, so that it will suffice to describe only one. The network including the timing gate generator **10**, the commutator **150**, and the integrator **174** is identical to that shown in FIG. **2** but has been included in FIG. **11** for convenience. The commutator **150** has the potentiometer input **156** representing x_1, and the potentiometer input **158** representing x_2. There is also shown a potentiometer input **550** representing x_{n-1} and an input **551** representing x_n. The input **551** is not a potentiometer input. Just as shown in FIG. **2**, the commutator **150** has inputs **164**, **166**, **168**, and **170** that receive signals from the timing gate generator **10** for gating the inputs **156**, **158**, **550**, and **551**. As previously described, the first of the succession of pulses in a given cycle from the timing gate generator **10** is fed through the conductors **270** and **272** to reset the integrator **174**. The second in the succession of pulses is fed through the conductors **276** and **277** to the input **164** of the commutator **150** gating the potentiometer input **156** through the conductor **172** to the integrator **174**. The integrated signal is fed through the conductors **20** and **114** and a conductor **552** to the input *a* of a track and hold network **553**. The track and hold network **553** also has an input *b* connected by a conductor **554** from an enable circuit **556**. The signal on the conductor **276** is also fed through a conductor **558** to the input of the enable circuit **556**. With a signal on the conductor **558**, the enable circuit **556** generates a signal which is fed through the conductor **554** to enable the track and hold network **553**. This will cause the network **553** to track the integrated output from the integrator **174** which, for the signal in the conductor **276**, corresponds to drawing the placement segment **307** (FIG. **3**) for a square. When the next of the sequence of pulses is generated by the timing gate generator **10**, the signal on the conductors **276** and **558** drop to zero, disabling the circuit **556** and causing the track and hold network **553** to hold its value. This value will be the final value of the placement segment, such as the segment **307**. This final value is fed through a conductor **559** to the minus input of a differential amplifier **560**. The next pulse generated by the timing gate generator **10** is fed through the conductors **282** and **284** to the input **166** of the commutator **150**, gating the potentiometer input **158** through the conductor **172** to the integrator **174**. The integrated output is then fed through the conductors **20** and **24** as heretofore described. This integrated output will not affect the track and hold network, **553** because it is no longer enabled. Each of the segments will be generated as heretofore described until the second to last segment is generated. The pulse from the timing gate generator **10**

that corresponds to the n-1 segment is fed through the conductors **290** and **292** to the input **168** of the commutator **150**, gating the potentiometer input **550**, which is the X voltage for the $n-1$ segment, through the conductor **172** on the integrator **174**. The integrated output is fed through the conductors **20** and **114** and a conductor **561** to the input *a* of a track and hold network **562**. The track and hold network **562** also has an input *b* connected by a conductor **564** to an enable circuit **566**. The pulse on the conductor **290** is also fed through a conductor **568** to the input of the enable circuit **566**. When the enable circuit **566** receives an input signal, an enable pulse is generated at its output which is fed through the conductor **564** to trigger the track and hold network **562**. This causes the network **562** to track the integrated output from the integrator **174** corresponding to the $n-1$ segment. When the last of the sequence of pulses is generated by the timing gate generator **10**, the signal on the conductors **290** and **568** goes to zero, disabling the circuit **566** causing the track and hold network **562** to hold its value. This value is equal to the final value of the $n-1$ segment. The value held by the track and hold network **562** is fed through a conductor **570** to the plus input of the differential amplifier **560**. The output of the differential amplifier **560**, which is equal to the difference between the final value of the second to last (n-1) line segment and the final value of the first line segment is fed through the conductors **118** and **551** to the input of the commutator **150** corresponding to the X signal for the nth line segment. The next and last of the sequence of pulses in the cycle generated by the time gate generator **10** is fed through the conductors **298** and **300** to the input **170** of the commutator **150** gating the feedback signal from the amplifier **560** through the conductor **172** to the integrator **174**. The integrated signal which is fed through the conductors **20** and **24** is the exact signal necessary to automatically close the figure.

The operation of the closure network can be explained with reference to the triangle of FIG. **12**. A triangle is a good figure to use as an example since its shape can be greatly varied while maintaining its basic configuration. The triangle of FIG. **12** has four line segments, **571**, **572**, **574**, and **576**. This figure can be easily animated by varying the length and/or direction of segments **571**, **572** and **574** with the segment **576** always being such that it will automatically close the figure. To generate this triangle, the timing gate generator **10** is programmed to generate a series of five pulses per cycle. Using only the X voltages for the purpose of this example, the X voltage for the segment **571** is set by the potentiometer input **156** to the commutator **150**, the X voltage corresponding to the line segment **572** is set by the potentiometer input **158**, and the X voltage for the line segment **574** is set by the potentiometer **550**. The first gate pulse from the generator **10** resets the integrator **174**. The second gate pulse from the generator **10** gates the potentiometer input voltage **156** for the line segment **571** through the commutator **150** and the conductor **172** to the integrator **174**. The second pulse also gates the enable circuit **556** which enables the track and hold circuit **553**, causing the circuit **553** to track the integrated waveform for the line segment **571** and to hold the final X coordinate value of the line segment **571**. The third pulse from the generator **10** gates the potentiometer input **158** for the line segment **572** through the commutator **150** and the conductor **172** to the integrator **174**. The integrated waveform for this line segment is fed through the conductors **20** and **24** as heretofore described. The fourth pulse from the generator **10** gates the potentiometer input **550** for the line segment **574**, which is the $n-1$ line segment, through the commutator **150** and the conductor **172** to the integrator **174**. The fourth pulse also gates the enable circuit **566** which enables the track and hold circuit **562**, causing the circuit **562** to track the integrated waveform for the line segment **574** and to hold the final X coordinate value of the line segment **574**. The final value of the line segment **571** and the final value of the line segment **574** are fed into the differential amplifier **560** which generates at its output the algebraic difference between these two final values. This algebraic difference is fed back to the input **551** of the commutator **150**. When the fifth and final pulse of the series is generated by the generator **10**, the feedback signal at the input **551** is gated through the commutator **150** and conductor **172** to the integrator **174**. This integrated output is the exact waveform necessary to generate the final line segment **576** to close the figure. This waveform is fed through the conductors **20** and **24** as heretofore described.

As previously explained, the automatic closure circuit for the Y coordinate voltages is identical to that just described. Therefore, by varying the potentiometer inputs **156**, **158**, and **550**, as well as the corresponding potentiometer inputs for the Y coordinate voltages animation can be imparted to the triangle of FIG. **12** resulting in great variations in its shape with the triangle always remaining closed.

A system has thus been described for generating and displaying two-dimensional figures and animating these figures in a variety of sequences. While the system has been generally described with reference to FIG. **1**, it is to be understood that not all of the features need be used at once. The network can easily be rearranged for use of only a portion of the system shown in FIG. **1** depending on the animation requirements.

Various changes and modifications may be made within the invention as will be readily apparent to those skilled in the art. Such changes and modifications are within the scope and teaching of this invention as defined by the claims appended hereto.

What is claimed is:

1. A system for generation, display and animation of two-dimensional figures comprising a display device for displaying the animated figure in response to coordinate inputs to the display device, means for generating first and second coordinate voltages for each line segment of the figure to be displayed, means for sequentially applying the first and second coordinate voltages to the coordinate inputs to the display device for sequential generation of the line segments of the figure, and means for animating the figure which last-named means comprises manually variable input means for defining the first and second coordinate voltages for each line segment of the figure to be displayed, whereby manual operation of selected ones of the manually variable input means over a given interval of time produces corresponding changes in the coordinate voltages being generated and hence the form of the figure being displayed over that same interval of time.

2. The system of claim 1 including a timing gate generator for generating a sequence of pulses to define a complete generation cycle, the number of the pulses being at least as great as the number of line segments in the figure to be displayed, means for establishing coordinate voltages for each line segment of the figure, means for gating the coordinate voltages in response to the sequential pulses of the timing gate generator for sequential generation of the line segments of the figure.

3. The system of claim 1 including means for regulating the intensity of each line segment.

4. The system of claim 2 including means for regulating the beam intensity of the display device for each of the line segments, the intensity means including means for establishing voltage inputs defining the intensity of each of the line segments, and means for gating the intensity voltages in response to the sequential pulses of the time gate generator for controlling the intensity of each line segment as it is generated.

5. The system of claim 1 including means for varying the gross position of the figure on the display device, which last-named means includes means for generating gross position voltage functions, and means for selectively adding the gross position voltage functions to the first and second coordinate voltages

6. A system for generation, display and animation of two-dimensional figures comprising a display device for displaying the animated figure in response to coordinate inputs to the display device, means for generating first and second coordinate voltages for each line segment of the figure to be displayed, means for sequentially applying the first and second coordinate voltages to the coordinate input to the display device for sequential generation of the line segments of the figure, means for selectively varying one or more of the first and second coordinate voltage over time thereby changing the form of the figure and producing animation, and means for automatically closing the figure as one or more first and second coordinate voltages are varied.

7. The system of claim 6 wherein the closing means includes means for automatically generating the last line segment of the figure to join the end of the second to last line segment to the end of a selected one of the previously generated line segments.

8. The system of claim 7 wherein the closing means further includes means for tracking the first and second coordinate waveforms of the selected one line segment and the second to last line segment of the figure, and for holding the voltage values corresponding to the ends of the selected one line segment and the second to last line segment, and means for generating a signal equal to the algebraic difference between the voltage values corresponding to the selected one line segment and the second to last line segment for use in generating the last line segment of the figure.

9. The system of claim 5 including means for rotating the figure about its point or origin, whereby the displayed figure can be made to roll across the screen of the display device.

10. The system of claim 9 wherein the rotating means includes means for transforming the first and second coordinate voltages to a second coordinate system rotated through a prescribed angle with respect to the original coordinate system, and means responsive to a voltage input function for defining the angle of rotation, whereby a variation in the voltage input produces a corresponding change in the angle of rotation.

11. A system for generation, display and animation of two-dimensional figures comprising a display device for displaying the animated figure in response to coordinate inputs to the display device, means for generating first and second coordinate voltages for each line segment of the figure to be displayed, means for sequentially applying the first and second coordinate voltages to the coordinate inputs of the display device for sequential generation of the line segments of the figure, means for selectively varying one or more of the first and second coordinate voltages thereby changing the form, size or position of the figure being displayed, and means for establishing boundary conditions that the figure cannot exceed as it is being animated.

12. The system of claim 11 wherein the boundary means includes means for generating signals defining the boundary conditions, means for detecting the coordinate voltages corresponding to the maximum degree the figure exceeds the boundary conditions, means for generating offset voltages equal to the difference between the detected voltages and the boundary condition voltages, and means for adding the offset voltages to the coordinate voltages as the figure exceeds the boundary conditions.

13. The system of claim 12 wherein the detecting means includes peck detectors for detecting and holding the voltages corresponding to the maximum degree the figure exceeds the boundary condition during one generation cycle.

14. The system of claim 13 wherein the boundary means includes dual networks for generating the offset voltages on alternate generation cycles.

15. A method of generating, displaying and animating two-dimensional figures comprising the steps of generating first and second coordinate voltages defining each line segment of the figure to be displayed, each of which coordinate voltages is established by manually variable input means, sequentially applying the first and second coordinate voltages to coordinate inputs of a display device for sequential generation of the line segments of the figure, and manually varying selected ones of the manually variable input means over a given time interval to animate the figure by producing corresponding changes in the coordinate voltages over the same time interval.

16. The method of claim 15 including the step of automatically closing the figure as one or more first and second coordinate voltages are varied.

17. The method of claim 16 wherein the closing step includes the step of automatically generating the last line segment of the figure to join the end of the second to last line segment to the end of a selected one of the previously generated line segments.

18. The method of claim 17 wherein the closing step further includes tracking the first and second coordinate waveforms of the selected one line segment and the second to last line segment of the figure, holding the voltage values corresponding to the ends of the selected one line segment and the second to last line segment, generating a signal equal to the algebraic difference between the voltage values corresponding to the selected one line segment and the second to last line segment, and generating the last line segment as

defined by the algebraic difference signal for automatically closing the figure.

19. The method of claim 15 including the step of establishing boundary conditions that the figure cannot exceed as it is animated.

20. The method of claim 19 wherein the establishing step includes the steps of generating signals defining the boundary conditions, detecting the coordinate voltages corresponding to the maximum degree the figure exceeds the boundary conditions, generating offset voltages equal to the difference between the detected voltages and the boundary condition voltages, and adding the offset voltages to the coordinate voltages as the figure exceeds the boundary conditions.

21. The method of claim 20 wherein the establishing means further includes the step of generating offset voltages for each generation cycle.

22. A method of generating, displaying and animating two-dimensional figures comprising the steps of generating first and second coordinate voltages defining each line segment of the figure to be displayed, sequentially applying the first and second coordinate voltages to coordinate inputs of a display device for sequential generation of the line segments of the figure, and automatically generating the last line segment of the figure to join the end of the second-to-last line segment to the end of a selected one of the previously generated line segments which last step further comprises tracking the first and second coordinate waveforms of the selected one line segment and the second-to-last line segment of the figure, holding the voltage values corresponding to the ends of the selected one line segment and the second-to-last line segment, generating a signal equal to the algebraic difference between the voltage values corresponding to the selected one line segment and the second-to-last line segment, and generating the last line segment as defined by the algebraic difference signal for automatically closing the figure.

23. A system for generation, display and animation of two-dimensional figures comprising a display device for displaying the animated figure in response to coordinate inputs to the display device, means for generating first and second coordinate voltages for each line segment of the figure to be displayed, means for sequentially applying the first and second coordinate voltages to the coordinate inputs to the display device for sequential generation of the line segments of the figure, means for varying selected ones of the coordinate voltages to animate the display by changing over time its shape, size or position, and means for defining the first and second coordinate voltages for at least one line segment of the figure in response to the first and second coordinate voltages of one or more of the other line segments of the figure regardless of the variations of the selected ones of the coordinate voltages, whereby at least one line segment is automatically generated in relation to one or more of the other line segments as the figure is animated.

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